

A Mechanically Steerable Array Antenna Using Controllable Dielectric Phase Shifters for 77 GHz Automotive Radar Systems

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Abstract

A mechanically steerable antenna using an adjustable dielectric phase shifter was designed and developed for automotive radar applications. We demonstrated that a movable dielectric slab placed on a coplanar waveguide (CPW) could be used as a phase shifter [1]. The required dielectric constant of $\epsilon_r = 5.6$ can be designed using a ceramic composite material. Numerical simulations using Ansoft HFSS and Designer were conducted at 77GHz. The microstrip transmission line to a WR-12 waveguide transition as the initial feeding point has also been investigated [2].

I. Introduction

Automobile collision avoidance radar has become a recent feature in automotive design. In order for automotive radar to be most effective, a combination of medium-range detection (in front of the car) and short-range detection (in all directions) is required. The 77 GHz collision avoidance radar in an automobile requires a beam scanning mechanism. One of the advantages of this newly proposed phase shifter design is that the whole antenna can be designed without using solid state phase shifters or MEMS devices.

In this paper, we propose that a movable dielectric slab added to a coplanar waveguide (CPW) can be used as a phase shifter. The radiation patterns of 3x8, 5x8, and 7x8 steerable array antennas with dielectric phase shifter were introduced at 77 GHz. The preset delay was added to a scan beam from -20° to $+20^\circ$.

II. Proposed Phase Shifter Based on a Movable Dielectric Slab

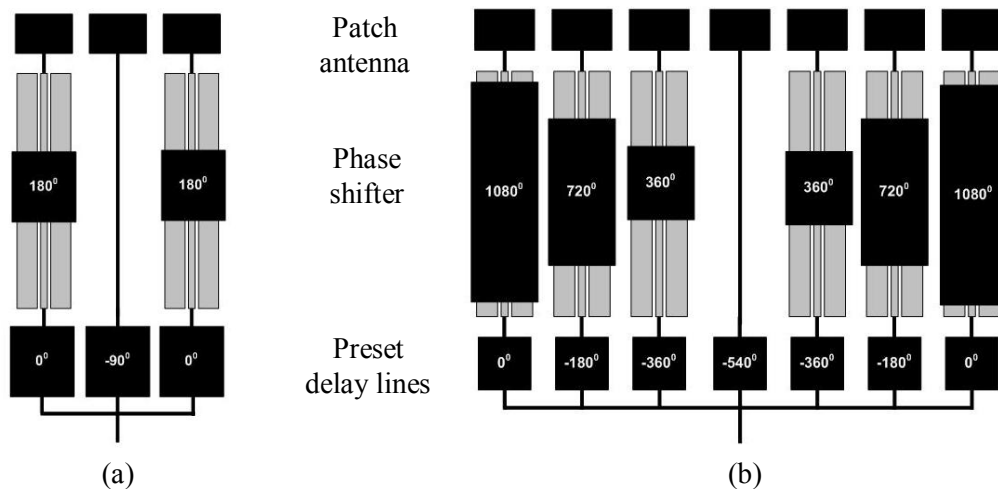


Fig. 1: (a) Block diagram of a 3x8 transmitting array antenna and (b) a 7x8 receiving array antenna.

Figure 1(a) and (b) show the transmitter antenna and receiver antenna, respectively. The antenna as a whole was composed of a patch antenna, a CPW (with or without a phase shifter), and preset delay lines. The element separations of the transmitter antenna and receiver antenna were set to 2.92 mm and 5.84 mm which corresponded to 0.75λ and 1.5λ , while the input impedance was 100Ω . The signal trace width of CPW was 0.5 mm and the ground width of CPW was 1.5 mm . The gap between the ground and the signal is 0.25 mm . The substrate has $\epsilon_{sub} = 2.2$ (Duroid 5880) and substrate thickness is 0.254 mm . The required dielectric constant of the dielectric material was $\epsilon_r = 5.6$. A ceramic composite material such as Duroid 6006 ($\epsilon_r = 6.1$) was suitable as the dielectric material with some adjustment. This is because when a dielectric slab is added to a CPW, it may produce a small residual gap (of less than $10 \mu\text{m}$) between the dielectric slabs and conductors. To minimize the reflection occurring when the dielectric material was added to the CPW, we set the length of the modified section to be $\lambda/2$ (or $m\lambda/2$ where m is an integer) [3]. The length of the dielectric material onto the CPW was 1.82 mm which corresponded to 180° . Similarly, the lengths of the dielectric materials on the CPW were 3.65 mm , 7.3 mm , and 10.95 mm which corresponded to 360° , 720° , and 1080° , respectively. In addition, preset delay lines were added to minimize the number of dielectric slabs. The preset delay lines at Fig. 1(a) were set to 0° , -90° , and 0° . The preset delay lines at Fig. 1(b) were set to 0° , -180° , -360° , -540° , -360° , -180° , and 0° .

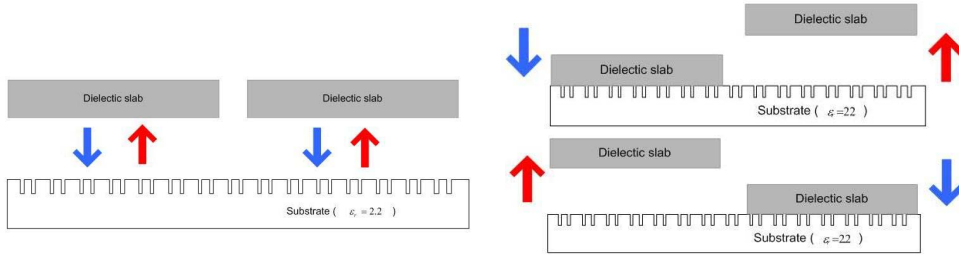


Fig. 2: Utilization of dielectric slabs on a CPW.

Fig. 2 illustrates how to utilize the dielectric slabs on a CPW. In order to scan the beam pattern, the dielectric slabs were inserted into the CPW. The effective dielectric constant and the characteristic impedance were calculated as a function of the movable dielectric slab position on the CPW transmission line. Fig. 2 shows the left and right dielectric slabs, based on the center transmission line. They alternated and were repeatedly inserted into the CPW. Depending on the way the dielectric slab is facing, the beam angle was scanned from -20 degrees to $+20$ degrees.

III. Layout of the Whole Antenna

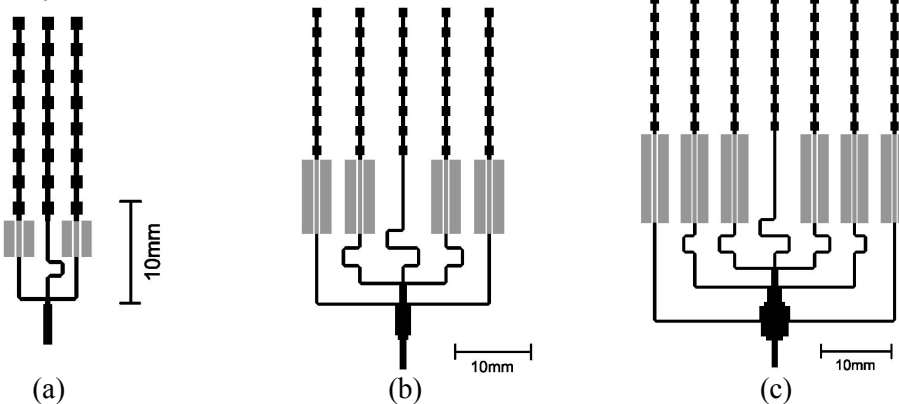


Fig. 3: Layout of the whole antenna. (a): 3x8 transmitting array antenna (b): 5x8 receiving array antenna (c): 7x8 receiving array antenna.

Fig. 3 illustrates the layout of the whole antenna. The width of the patch was 1.155mm and the height was 1.27 mm. The width of the transmission was 0.5 mm and the spacing between the patches was 1.4 mm. The bottom layer of the CPW section did not have a ground plane and via was used for connecting to the ground. In order to distribute power equally, 3-way, 5-way, and 7-way power dividers were optimized. In addition, for the initial feeding position, a microstrip line to the WR-12 waveguide transition was used.

IV. Numerical Results

Figures 4 to 6 illustrate the radiation patterns when the dielectric slabs alternate and are repeatedly inserted into the CPW. The expected beam scan angle was from -20° to $+20^{\circ}$. Fig. 7 shows the radiation patterns of both the transmitted and the received combined response. The large side lobe is a result of the grating lobe in the receiving antenna.

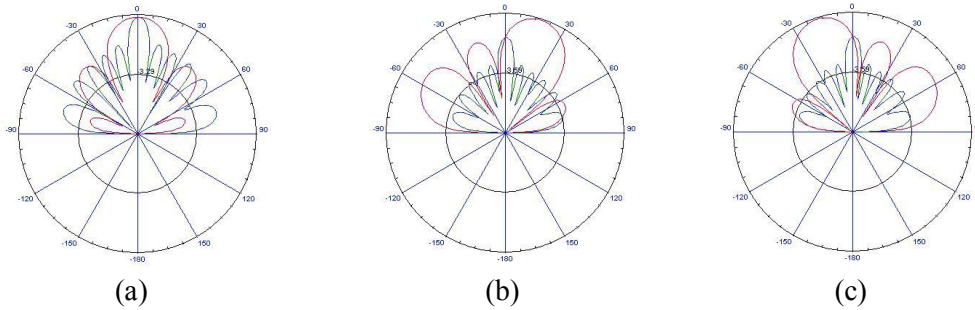


Fig. 4: Radiation patterns of a 3x8 array antenna. (a): Radiation patterns occurring when there were no delays lines and no phase shifters. (b): Radiation patterns occurring when the dielectric slab (180°) was only inserted into the left CPW. (c): Radiation patterns occurring when the dielectric slab (180°) was only inserted into the right CPW.

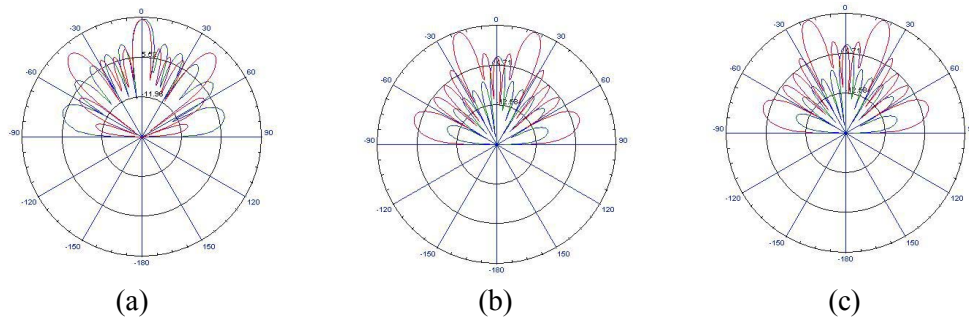


Fig. 5: Radiation patterns of a 5x8 array antenna. (a): Radiation patterns occurring when there were no delays lines and no phase shifters. (b): Radiation patterns occurring when the dielectric slab (360° and 720°) was only inserted into the left CPW. (c): Radiation patterns occurring when the dielectric slab (360° and 720°) was only inserted into the right CPW.

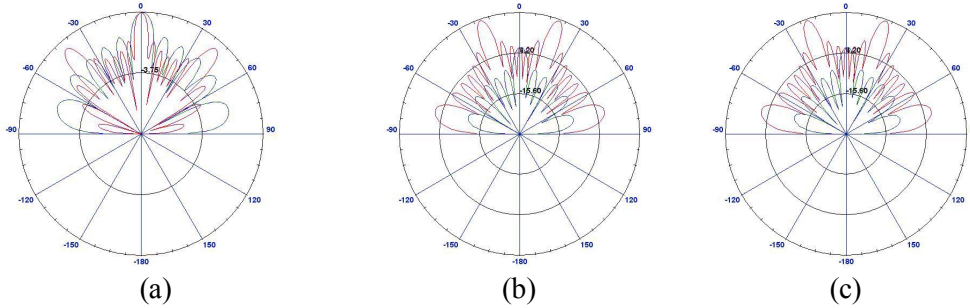


Fig. 6: Radiation patterns of a 7x8 array antenna. (a): Radiation patterns occurring when there were no delay lines and no phase shifters. (b): Radiation patterns occurring when the dielectric slab (360° , 720° and 1080°) was only inserted into the left CPW (c): Radiation patterns occurring when the dielectric slab (360° , 720° and 1080°) was only inserted into the right CPW.

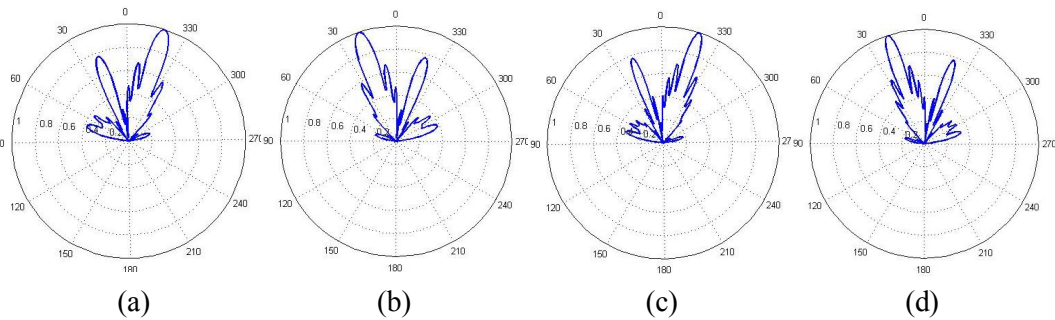


Fig. 7: Combined radiation patterns. (a): Combined radiation patterns with a 3x8 transmitting array antenna (Fig. 4(b)) and a 5x8 receiving array antenna (Fig. 5(b)). (b): Combined radiation patterns with a 3x8 transmitting array antenna (Fig. 4(c)) and a 5x8 receiving antenna (Fig. 5(c)). (c): Combined radiation patterns with a 3x8 transmitting array antenna (Fig. 4(b)) and a 7x8 receiving array antenna (Fig. 6(b)). (d) Combined radiation patterns with a 3x8 transmitting array antenna (Fig. 4(c)) and a 7x8 receiving array antenna (Fig. 6(c)).

V. Conclusions

A mechanically steerable array antenna using a dielectric phase shifter was proposed. The proposed array antenna with phase shifters may be suited for applications in automotive radar systems. As the dielectric slab was inserted into the CPW in an alternating and repetitive fashion, the beam angle was able to be scanned from -20° to $+20^\circ$. Future steps involve the design and testing of a microstrip line to a waveguide transition. The waveguide transition would be on a single layered dielectric substrate, as the initial feeding position.

References

1. J. Cha, Y. Kuga, and J. T. Kajiya, "A Mechanically Steerable Array Antenna with Controllable Microwave Phase Shifters at 20 GHz," 2005 IEEE AP-S International Symposium, vol. 3A, pp. 691-694, July 3-8, Washington D.C.
2. H. Iizuka, T. Watanabe, K. Sato, K. Nishikawa, "Millimeter-Wave Microstrip Line to Waveguide Transition Fabricated on a Single Layer Dielectric Substrate," R&D Review of Toyota CRDL vol. 37, No. 2, 2002.
3. Y. Kuga, J. Cha, J. A. Ritcey, and J. T. Kajiya, "Mechanically Steerable Antenna Using Dielectric Phase Shifters," 2004 IEEE AP-S International Symposium, vol. 1, pp. 161-164, June 20-26, Monterey, CA.